MODELLING HOLM OAK ACORN PRODUCTION IN SOUTH-WESTERN IBERIA

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Introduction

Since old times the production of acorn by the oak trees has been of high interest for human and animal consumption (Fernández-Rebollo and Carbonero-Muñoz, 2008). An important source of these acorns are *Dehesas* and *Montados* which are typical agroforestry systems of the Mediterranean region characterized by the presence of wooded pastures under holm oak (*Quercus ilex* L. or *Quercus rotundifolia* L.) and cork oak (*Quercus suber* L.). These systems are focused on livestock extensive production, where the acorns play an important role in the energy demand of livestock, a wide range of wild animals, but also for future interest in human consumption (Pintado, 2015.)

However, acorn production is highly variable between years, geographic locations and even between nearby trees. This variability is a source of uncertainty and a challenge for modelling the production of acorns. Nevertheless, this work focused on a preliminary method to project acorn productivity at a daily time step to complement the energy availability of the system to estimate livestock carrying capacity.

Considering a process-based modelling approach, the main objectives of this study are: 1) to develop a methodology to estimate acorn productivity in *Quercus ilex* L based on crown cover size of trees; 2) to integrate the method into Yield-SAFE, an agroforestry process-based growth model (van der Werf et al. 2007) and 3) compare acorn productions between stands and locations while estimating animal carrying capacity of the system by considering the metabolisable energy from acorns and grass.

Material and methods

The Yield-SAFE model (YS), a biophysical model that describes tree and crop growth in arable, forestry, and agroforestry systems according to light and water availability, was calibrated for *Quercus ilex* and grasslands in *dehesas* systems.

The fruit module was implemented into YS following the suggestion of Gea-Izquierdo et al (2006) by linking the acorn productivity to the crown cover size. The fruit productivity parameter (F_p, in g m^{-2} of canopy cover) was included in YS and linked to the *CanopyCover* state variable that is defined as the area of the ground covered by the vertical projection of the canopy of the tree (in m^2). A reference value of 100 g m^{-2} was considered as average acorn production for *Quercus ilex* in Spain (Gea-Izquierdo et al 2006).

Fruit fall seasonality was also taken into account by considering the number of days when the fruit is falling (FF_{Span} in days) and the fruit falling peak day (FF_{Peak} in day of year). For *Quercus ilex* acorn is expected to fall for 100 days, from 15th September to 23th of December with fruit peak the 3rd of November (Cañellas et al 2007). Given this fruit seasonality, daily probabilities of acorns to fall (FFP_{DOY}) were calculated using a normal distribution function where FF_{Peak} is the average and the standard deviation defined as $FF_{Span}/4$, meaning that 95% of the probability of acorn fall is included in the FF_{Span} number of days.

$$FFP_{DOYnorm} = \frac{1}{\frac{FF_{Span}}{4}\sqrt{2\pi}} e^{-\frac{(DOY_{norm}-FF_{Peak})^2}{2(\frac{FF_{Span}}{4})^2}}$$

Once the daily fruit availability is estimated, the daily fruit production (DFP_{DOY} in kg $ha^{-1}day^{-1}$) was calculated as:

$$DFP_{DOYNORM} = CanopyCover_{DOY} * (F_p/1000) * (\rho_t * 10000) * FFP_{DOYNORM}$$

Where ρ_t is the tree density of the stand (trees m^{-2}).

The Annual fruit production (AFP in kg ha^{-1}year^{-1}) was calculated as the sum of the Daily fruit production for the period of time where there is a fruit fall (when $FFP_{DOYnorm}$ is > 0.00001) as:

$$If\ FFP_{DOYNORM} < 0.00001, then, AFP = 0$$

$$If\ FFP_{DOYNORM} > 0.00001, then, AFP = DFP_{DOYNORM} + DFP_{DOYNORM-1}$$

The potential daily carrying capacity of the system was calculated as the sum of the metabolisable energy content from fruit (F_{ec} in MJ Mg^{-1}) and grass (C_{ec} in MJ Mg^{-1}), and compared to the reference livestock unit energy requirement (LUER) of 103 MJ day^{-1} (Hodgson, 1990). The metabolizable energy content for acorn and grass considered were 7230 MJ Mg^{-1} (Lopez-Bote et al 2000) and 9750 MJ Mg^{-1} (Köster et al, 2004) respectively.
Finally the sequential days of carrying capacity expresses the number of following days the system is able to supply the energy requirements for a selected livestock species. In *dehesas* with Iberian pigs, the sequential number of days is of high relevance as animals need to free graze for at least 40 days in order to receive the Protected Designation of Origin (PDO) certificate.
The methodology was then validated in two different sites in south-west Iberia: Badajoz and Cáceres. In Badajoz acorn productivity was studied during the years 1997-1999 having an average of 680 kg ha^{-1}year^{-1} (15.1 kg tree^{-1} year^{-1}). The area has a tree density up to 45 trees ha^{-1} with a loam soil texture (Cañellas et al 2007). The experimental site in Cáceres has an average density of 25 trees ha^{-1} with average acorn productions of 365 kg ha^{-1}year^{-1} (14.6 kg tree^{-1} year-1) and deep sandy-loam soils. In both cases weather information was obtained with the Clipick tool (Palma, 2015).

Results
With the YieldSAFE simulation of 25 trees ha^{-1} holm oak stands over a period of 100 years in the area of Cáceres site, first results showed reasonable estimations for height, dbh, tree biomass and stand compared to those observed: height of 8.1 +- 1.3m; DBH of 44.9 +-6.4 cm; tree biomass of 1056 kg tree^{-1} and stand biomass of 26.4 Mg ha^{-1} (Moreno, personal communication, 2016; **Figure 1**, top).
Results were also consistent with previous studies for grass production estimations. YS estimated productions of around 1.44 Mg ha^{-1} for Badajoz site and 1.22 Mg ha^{-1} for Cáceres site. Similar values to the average grass production for non-fertilized grasslands of the region of 1.4 Mg ha^{-1} (Moreno et al 2007; Figure 1 centre).
The values obtained for acorn production fit well with the results observed for the two experimental sites. In year 100, representing a mature system, an annual production of 620 kg ha^{-1} year^{-1} and 367 kg ha^{-1} year^{-1} is estimated for Badajoz and Cáceres respectively. These estimations are close to the observed values between 590 and 830 kg ha^{-1} in Badajoz and to the average 365 kg ha-1 observed in Cáceres (Figure 1 centre). Also the results are similar to the results obtained in previous studies in *dehesa* systems: Gea-Izquierdo (2006) reported productions of around 250-600 kg ha-1 in a system with 50 tree ha^{-1}, and other authors reported average values around 550 kg ha^{-1} (Cañellas et al, 2007; Fernández-Rebollo and Carbonero-Muñoz, 2007).

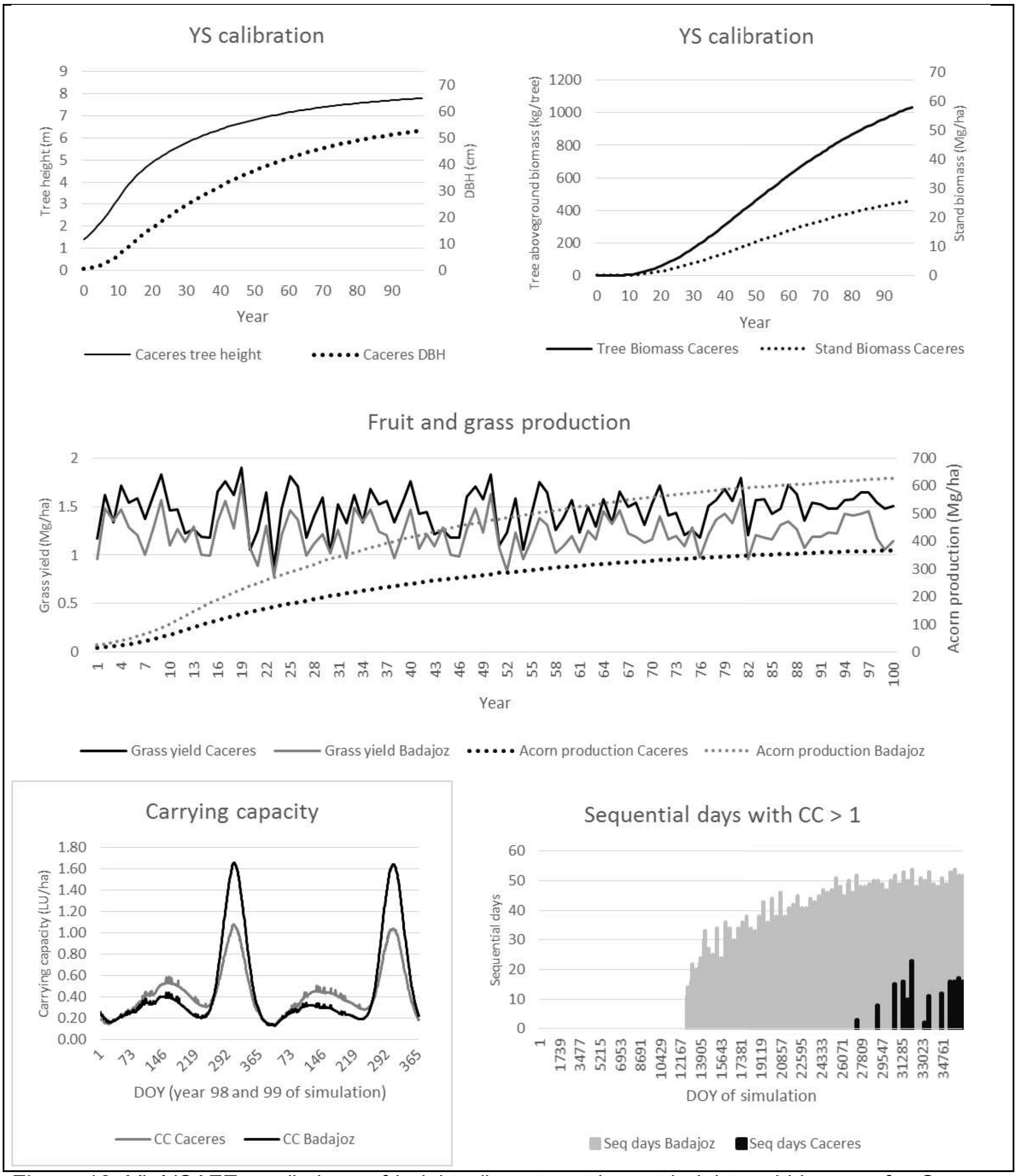

Figure 13: YieldSAFE predictions of height, diameter at breast height and biomass for Quercus ilex (top). Simulated acorn and grass production for Cáceres and Badajoz sites (centre). Carrying capacity of the systems for years 99 and 100 considering fruit and grass availability for Cáceres and Badajoz sites and number of sequential days the system can feed Iberian pigs (bottom).

Considering the 48 MJ day^{-1} energy requirements of an Iberian pig (Lopez-Bote et al 2000) both sites present similar annual carrying capacity values (0.39 LU ha^{-1} and 0.41 LU ha^{-1} for Cáceres and Badajoz respectively) and seem to be consistent with the carrying capacity reported for the region of 0.3 LU ha-1 (Moreno, personal communication, 2015). The sequential days of carrying capacity expresses the number of following days the system is able to supply the energy requirements for one Iberian pig (i.e. 0.47 livestock units) - what in Spanish/Portuguese is called *montanera/montanheira*). For Badajoz site, as fruit production is higher, the system is able to support more than 40 sequential days in year 60, while in Cáceres the system supports up to 15 sequential days in year 100 of simulation (Figure 1 bottom).

Discussion

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The methodology proposed allows the YieldSAFE model to simulate long-term acorn fruit production from *dehesas* agroforestry systems. Although the model is not sensitive to the high variability of acorn production, the long-term prediction matches well the values reported in the literature. Furthermore, the estimation of fruit production linked to data on utilisable metabolizable energy provided a coherent estimation of the carrying capacity for Iberian pigs. These first results seem to offer consistent information related to the potential carrying capacity of *dehesa/montado* systems,that will enable future assessments of land management scenarios to improve the provisioning of food and materials. Due to its simple approach, the proposed methodology can be transferred to other silvopastoral systems in Europe, developed under the AGFORWARD project (Burgess et al 2015).

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